Relation between Neutral Gas Flux Density and Parameters of the Scrape-Off Layer

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INTRODUCTION

Asdex Upgrade (AUG) diagnostic data has been compiled in a SAS-formated database which includes beside various global discharge parameters local ones of the plasma edge, the scrape-off layer (SOL) and the divertor. Especially measurements of T_e and n_e profiles with high spatially resolution have been recently included, which permit now a detailed statistical analyses of the inter-relation of various edge parameters and their relation to global ones.

Radial $n_e(r)$ profiles in the SOL (Scrape-Off-Layer) are measured routinely by means of a lithium beam probe. For a limited number of discharges the position of the Thomson scattering system was optimised for measurements (T_e) in the plasma edge. All T_e measurements presented here originate from these measurements.

The relation between the neutral gas flux density Γ_0 in the divertor measured by ionisation gauges and the midplane averaged SOL density $(n_e^{SOL} = 1/L^{SOL} \cdot \int n_e(r)\,dr)$ will be discussed in chapt. 1

One major concern of investigations dealing with the plasma edge and the SOL is the radial position of the last closed flux surface (separatrix). In general the separatrix position at AUG is magnetically determined within an uncertainty of ± 5 mm. By assuming classical parallel heat conduction between midplane and divertor and with an estimate of the radial power flow across the separatrix, a midplane separatrix temperature can be predicted [1]. Within this assumptions a procedure to test the quality of the magnetically defined separatrix position will be described in chapt. 2.

By this means we investigate dependencies between edge parameters. Especially an T_e^{sep}, n_e^{sep} - diagram including all AUG discharge regimes helps to recognise the available operational space.

DIVERTOR NEUTRAL GAS FLUX DENSITY and n_e^{SOL}

The relation between neutral gas flux density Γ_0 in the divertor and midplane density profile parameters like n_e^{sep}, λ_{ne} and n_e^{SOL} seems to be of rather general nature [2]. Especially n_e^{sep} and n_e^{SOL} increase in a power law regression analysis with $\Gamma_0^{0.5}$ However, systematic deviations from this general behaviour are found.

In clean high density H-mode discharges near the H->L back-transition a considerable weaker increase of n_e^{sep} with $\Gamma_0^{0.2}$ has been observed [3], whereas n_e^{SOL} obeyed the general relation $(n_e^{SOL} \propto \Gamma_0^{0.5} q_{95}^{0.4}$, q_{95} ... safety factor). In these discharges the line averaged density saturated and could not be raised by gas puff which lead only to increased Γ_0, and n_e^{SOL} and most unwanted to a degratation of confinement [4].

In discharges with additional impurity puffs (Ne or N_2) the situation is quiet different (cf. fig. 1). In cases with considerable impurity puff no dependency of n_e^{SOL} with Γ_0 is observed. In addition, n_e^{SOL} values are within a rather small range of $1.8 - 2.2 \cdot 10^{19}$ m^{-3} for nitrogen (I_p = 1MA, P_{heat}=7MW, $\Gamma_{nitrogen} = 6.0 - 12 \cdot 10^{21}$ atoms/s) as well as for neon puffed cases (I_p = 0.8MA,1MA, P_{heat}=5-8MW, Γ_{neon} feedback controlled). These discharges are compared with two discharges (I_p = 0.8MA, P_{heat}=2.5,7.5MW) without additional impurity puff in fig.1. and one with only moderate N_2 puff ($4.0 \cdot 10^{21}$ atoms/s). All of them obey the general relation found for the high recycling regime. Towards lower n_e^{SOL} and Γ_0 values the high recycling regime is left which is indicated by the deviation of measured points from the straight line in fig. 1. In the low recycling regime a linear dependency of n_e^{sep} and n_e^{SOL} with Γ_0 has been found [2]. This transition region depends on the applied heating power and occurs in ohmic cases therefore at much lower Γ_0 values [2].

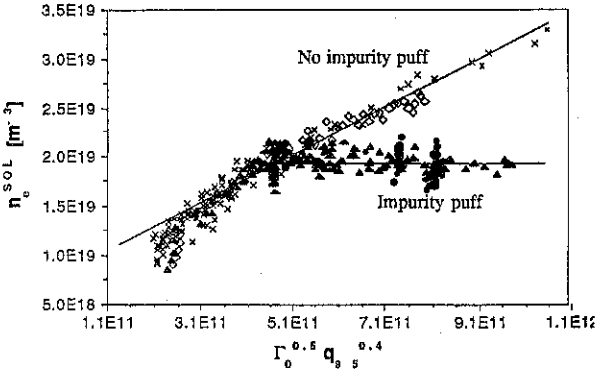

Fig. 1: Line averaged SOL density n_e^{SOL} vs. the result of a regression analysis (cf. text and [2]) for Deuterium discharges with and without additional impurity puffing. (X...D_2 only, ◇...moderate N_2 puff, ▲...N_2 puff, ■...Ne puff, lines to guide the eye.)

It is well known that puffing of impurities which preferentially radiate in the plasma edge and SOL help to reach the detached plasma regime. One might speculate that in the detached regime Γ_0 and n_e^{SOL} and thus also n_e^{sep} become completely decoupled and the SOL density becomes even independent at least in a first approximation from global discharge parameters.

In contradiction to the case of clean high density H-mode discharges the line averaged density in impurity puffed discharges (H-mode or CDH-mode) is stronger influenced by Γ_0.

SEPARATRIX POSITION TESTED by SOL MODEL

A 1.5D - model predicts a temperature at the separatrix (T_e^{mod}) and an exponential fall-off length λ_{T_e} for the temperature profile in the SOL [1]. By combination of this two results the following formula for the separatrix temperature T_e^{mod} can be derived,

$$T_e^{mod}\,[\mathrm{eV}] = \alpha \cdot \left[\frac{P_{SOL}[\mathrm{W}]\, q_{95}^{\,2}}{\lambda_{T_e}[\mathrm{cm}]} \right]^{2/7} \qquad (1)$$

where P_{SOL} denotes the power crossing the separatrix. The parameter α involves geometric factors like the plasma surface at separatrix radius and an averaged connection length between midplane and the divertor plates and can be determined by a linear regression fit. Such a fit ($R^2=0.93$) applied to a set of discharges covering almost the complete operational space of AUG, delivers $\alpha = 0.5$, where we used for P_{SOL} approximately P_{heat} - P_{rad}.

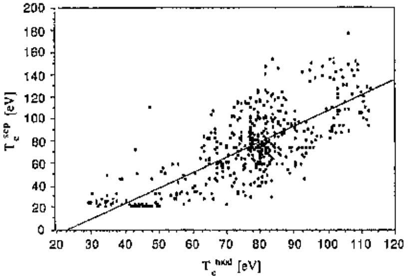

Fig. 2a: Measured separatrix temperature T_e^{sep} vs. T_e^{mod}, predicted by equ. 1.

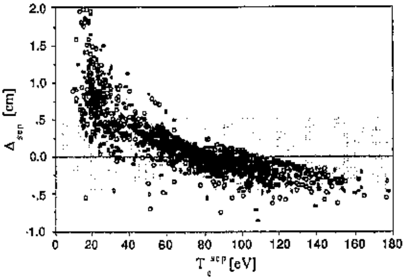

Fig. 2b: Shift in separatrix position to achieve $T_e^{sep} = T_e^{mod}$ (cf. text).

T_e^{mod} values cover a range from 30 - 115 eV, whereas measured T_e^{sep} values occur between 20 and 180 eV (cf. fig. 2a). Assuming the difference in both T_e values is due to an inaccurate magnetically defined separatrix position a shift Δ_{sep} of the latter can be estimated by $\Delta_{sep} = \lambda_{Te} \cdot [\ln(T_e^{mod}) - \ln(T_e^{sep})]$. Most of all Δ_{sep} values lie within ±5mm (cf. grey area in fig. 2b) in the high temperature range (T_e > 60 eV, cf. fig. 2b), which corresponds to the error in the magnetic separatrix position.

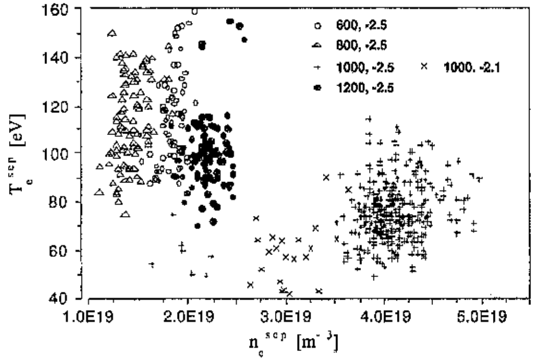

Fig. 3a: Measured T_e^{sep} vs. measured n_e^{sep} for H-Mode discharges ($4.7 < P_{heat} < 5.3$ MW, B_T=-2.1,-2.5 T, I_p=0.6-1.2MA).

For lower temperatures, however, shifts up to 1.5cm would be necessary to identify the T_e^{mod} value in the measured T_e-profile. This systematic increase of an inside shift of the separatrix position for lower T_e indicates the limit of applicability of the assumed model. In this low temperature region radiation zones above the target plates reduce the effective length along power has to be conducted which is not represented in the present model. Therefore, as long as Δ_{sep} is not in contradiction with the magnetic separatrix position the model can be used to correct the separatrix position. In the following only data is presented where magnetic and model derived separatrix are within ±5mm. The derived shifts Δ_{sep} can also be used to correct other separatrix parameters as e.g. measured n_e^{sep} data by $n_e^{cor} = n_e^{sep} \cdot \exp[\Delta_{sep} / \lambda_{ne}]$. Because λ_{ne} is considerable bigger than λ_{Te} this correction leads only to changes of less than 10%.

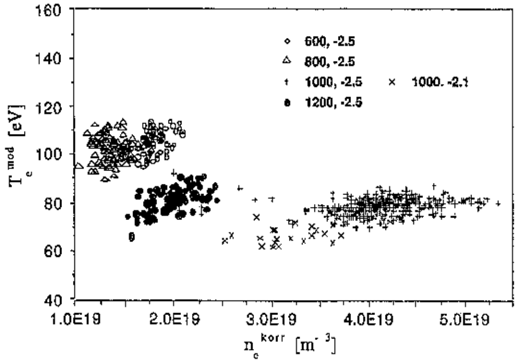

Fig. 3b: T_e^{mod} vs. n_e^{cor}, corrected for separatrix position, same discharges as in fig. 3a

In Fig. 3 a,b we compare original T_e, n_e (fig. 3a) data with "separatrix corrected" ones (fig. 3b) for a set of H-mode discharges where P_{heat} was restricted to values between 4.7 and 5.3 MW and primarily safety factor $q \propto B_T/I_P$ and density are varied. The dominant effect of the correction process is to reduce the scatter in the data. General trends, e.g. the q-dependence of T_e values recognised already in the original data are emphasised by the separatrix correction.

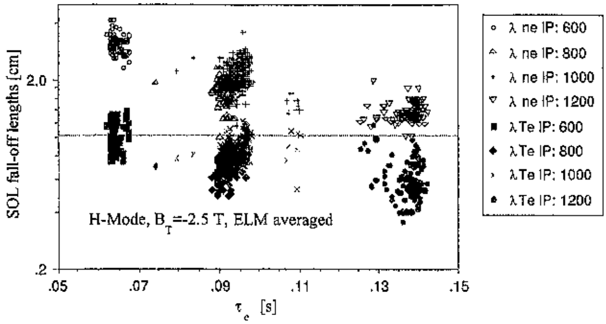

Fig. 4: SOL fall-off-lengths for temperature and density. H-Mode dataset with B_T=-2.5T, P_{heat}=4.7-5.3 MW. and variation in q (Plasma current IP in kA)

Fall-off-lengths of temperature λ_{Te} and density λ_{ne} (3-4 times larger as λ_{Te}) can be ordered by plasma current I_P or safety factor q (no B_T variation) and energy confinement time Thus even parameters outside closed flux surfaces seem to be connected to the global confinement behaviour of a discharge.

CONCLUSIONS

In clean H-mode discharges confinement deteriorates with increasing Γ_0 [4]. In addition n_e^{SOL} increases with Γ_0 and T_e^{sep} shows only a weak dependence on n_e^{sep}. Thus, the screening effect for neutrals in the SOL will increase and the density of neutrals on closed flux surfaces will even decrease when Γ_0 is raised [3], leading besides changes in confinement also to a limit of particle fuelling by gas puff. Therefore higher Γ_0 can hardly be the direct physical reason for the degradation of H-mode confinement. However, raising Γ_0 certainly changes the boundary conditions for the edge plasma where the H-mode barrier is located. Therefore Γ_0 must be correlated with key parameters for H-mode confinement (e.g. p_e or ∇p_e or fall-off-lengths λ_{Te}, λ_{ne}) which have to be identified by future analysis.

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